The Svalbard Experimental Oilspill Field Trials

G.A. Sergy
Environment Canada
Emergencies Science Division
Edmonton, AB, Canada
gary.sergy@ec.gc.ca

C.C. Guénette
SINTEF Applied Chemistry
Environment Engineering
Trondheim, Norway

E.H. Owens
Owens Coastal Consultants
Bainbridge Island, WA, U.S.A

R.C. Prince
Exxon Research and Engineering Co.
Annandale, NJ, U.S.A

K. Lee
Fisheries and Oceans Canada
Maurice Lamontagne Institute
Mont-Joli, QC, Canada

in Proceedings of the Twenty-First Arctic Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, Ontario, pp 873-889, 1998.

Abstract

An experimental oil spill was held on Svalbard, Norway, during the summer of 1997, with the objective to quantify the effectiveness of selected *in situ* shoreline treatment options appropriate to accelerate natural oil removal processes on mixed sediment shorelines. The project is a component of the international *In situ* Treatment of Oiled Sediment Shorelines (ITOSS) Programme. The 1997 Svalbard Shoreline Field Trials were successful. Oiling of the shorelines, treatment of oiled plots, and sampling went as planned. This paper describes the operational and scientific components of the field program.

Three shoreline segments were oiled, and experimental plots were established within the continuous stretch of oiled shoreline at each of the three sites. A total of 5500 L of oil were applied to a 3m wide swath in the upper intertidal zone. Treatments were conducted approximately one week after oiling following wave and tidal washing.

Treatments included *in situ* tilling (mixing), sediment relocation (surf washing) and bioremediation. The nature of oiling and treatment protocols were similar to that of actual spill response operations. Monitoring of the quantity of oil lost from the plots was conducted at six time periods with the last at 60 days after treatment. To overcome sediment and oiling heterogeneity, TPH was determined using a multiple large sample sediment technique developed previously. A variety of other measurements were carried out to document changes in beach physical character, oil penetration, movement of oil to the subtidal environment, toxicity and oil biodegradation.

1.0 Introduction

The *In situ* Treatment of Oiled Sediment Shorelines (ITOSS) Programme was initiated to investigate the effectiveness of several mainstream *in situ* shoreline cleanup options appropriate to accelerate natural oil removal processes on mixed-sediment (sand and pebble) shorelines. *In situ* methods refer to a group of techniques that treat oil in place without the removal or recovery of oil or oiled materials from that location. In many cases, these are techniques that accelerate or enhance natural oil removal processes, such as mechanical abrasion of oil, weathering or biodegradation. *In situ* options may be applied anywhere in the world and on various types of beaches and stranded oils, but are particularly attractive for remote or inaccessible areas, such as are common on the coasts of northern Canada, Russia, Scandinavia, and Alaska.

The primary component studies of the ITOSS Programme were:

- the 'Svalbard Shoreline Field Trials', a full scale experimental oil spill conducted on the shorelines of Svalbard Norway, and,
- the 'Beach Basin Trials', in which meso-scale experiments were conducted in simulated beach basins at SINTEF facilities in Trondheim, Norway and the COSS (Coastal Oilspill Simulation System) facility in Corpus Christi, Texas (Sergy *et al.*, 1997).

The Programme design involved a series of experiments at different scales. The Trondheim and COSS trials were small (1 x 2 x 4 m) and large (2 x 2 x 33 m) mesocosm studies with some ability to control environmental variables. The Svalbard shoreline field trials were a full-scale oilspill experiment with all the environmental variables in play. This paper will focus on the 1997 Svalbard Field Trials, and specifically on the methodology of the trials.

2.0 Background and Rational

2.1 Shoreline Treatment Methods

A number of treatment methods can accelerate the recovery of oiled beaches. One method is to physically remove oiled material using earth-moving equipment or manual techniques. The primary disadvantage of physical removal is the high volume of waste material that is generated and then requires disposal. Oiled sediments rarely contain more than 1 per cent oil-in-sediment by weight, and usually the concentrations are an order of magnitude lower, so that relatively little oil is removed for a large volume of sediment removal. This technique is particularly disadvantageous in remote regions, where waste storage, transfer, and disposal can be significant operational constraints. A second disadvantage is that removed sediment may not be replaced rapidly by natural coastal processes, thereby potentially temporarily or permanently depleting the sediment budget of a beach with resulting beach and shoreline retreat (erosion).

Instead of collecting the spilled oil, *in situ* treatment methods treat the oil and oiled materials in place. Therefore a key feature of this group of techniques is that no oiled materials are generated or recovered that require transfer and disposal.

Physical *in situ* shoreline treatment methods include mixing (also known as tilling or aeration), sediment relocation (or "surf washing"), and burning. This group of techniques involves physical, on-site treatment techniques to alter the character of the oil or to change the location of the oil with respect to the intertidal zone in order to promote or increase weathering and natural degradation. Chemical and biological *in situ* shoreline treatment methods include the use of dispersants, or nutrient enhancement / bioremediation.

The ITOSS Programme included trials to evaluate the *in situ* treatment methods of sediment relocation, tilling and bioremediation. **Sediment relocation** involves the movement of material from one section of a beach to another to accelerate the natural physical removal of oil from the sediments. This method usually involves the movement of oiled materials from the higher sections to lower parts of the intertidal zone, where levels of wave action are greater, due to the longer period of submersion. In some instances this action may involve movement of material stranded on berms above the normal limit of wave action, for example by storm waves or during high spring tides.

Tilling involves the break up of surface oil or the excavation of subsurface material to expose either buried oil or oil that has penetrated in beach sediments. In some cases material is moved aside to expose the subsurface oil, but, in essence, the materials are not relocated to another section of the beach. This exposure to atmospheric, wave, and tidal processes is intended to accelerate the natural removal of oil from the beach.

Bioremediation aims to stimulate the natural biodegradation of spilled oil. Oil degrading microbes are ubiquitous in the marine environment (Prince, 1994), but their growth after an oil spill is typically limited by the availability of biologically useful nitrogen and phosphorus. Bioremediation by the application of fertilizers to partially alleviate this limitation was used successfully after the *Exxon Valdez* spill to stimulate the rate of biodegradation some 2- to 5-fold (Prince and Bragg, 1997). The bioremediation strategy at Svalbard involved the addition of soluble and slow-release fertilizer to tilled and untilled plots.

2.2 Previous Studies

Sediment relocation, or surf washing, has been used many times on spills throughout the world, using either heavy equipment (Owens *et al.*, 1995) or manual labour (Molden, 1997). However, little information exists in the literature and, until recently, few data have been collected. Sediment relocation was carried out on 30 beaches in Prince William Sound in 1990, and topographic profiles were surveyed before and after these activities (Owens *et al.*, 1991), but no hydrocarbon data were collected during this study. Visual observations indicated that these relocation treatment actions were successful in reducing oil residues. More recently, surf washing was conducted on the 1996 *Sea Empress* spill in 1996 at Amroth, South Wales. After four days of relocation treatment, the concentrations of oil on this beach were reduced by more than an order of magnitude (Lee *et al.*, 1997; Lunel *et al.*, 1996).

Tilling is a practice that has been used on land for many years and occasionally on beaches, but virtually no data have been collected on the effects of this action to accelerate the natural weathering of stranded oil. One limited study was carried out during the Baffin Island Oil Spill (BIOS) project (Owens *et al.*, 1987) and this indicated that the mixing action, using a portable roto-tiller on 10m x 2m plots, increased surface hydrocarbon concentrations over the short term (one to two weeks). Tilling was conducted at a number of locations in Prince William Sound during 1990 and 1991 to expose buried oil or oil that had penetrated into coarse beach sediments. Visual observations indicated that these treatment actions were successful in reducing oil residues.

The state-of-knowledge for sediment relocation and tilling can be summarized as one in which the objectives, actions, and results are well understood, but are not substantiated by data that can be used to assess amounts or rates of change associated with these two treatment techniques or associated with different environmental variables, such as waves and tides.

Related, but even less well understood, is a process which may enhance or accelerate the rate of oil removal of sediment relocation and tilling. The concept of an interaction between stranded oil and fine particles (termed Oil-Fines Interaction or OFI) has received some attention in recent years. In the natural environment, the process has been investigated in the context of field samples collected from a number of past spills (*Exxon Valdez*, *Arrow*, *Metula*, *Nosac Forest*, Tampa Bay, BIOS) and more recently on the *Sea Empress*. This process may explain why and how oil is removed naturally from surface and subsurface sediments in areas where natural wave energy levels are too low to physically or mechanically abrade residual oil (Bragg and Owens, 1995).

3.0 Field Trials Objective

The primary objective of the Svalbard shoreline experimental oilspill was to quantify the effectiveness of *in situ* shoreline treatment options that are used to accelerate the natural processes that remove oil stranded on mixed coarse sediment beaches. Specific sub-objectives were therefore related to selected treatments and their affect on the fate of the oil in order to answer practical issues related to the choice of sediment relocation, tilling, bioremediation and natural removal as suitable response options. Specifically, seven questions were posed:

- does the relocation of oiled sediments from at, or above, the mean high water line to the lower intertidal zone increase the rate of oil removal from the beach?
- does the mixing of the oiled layer of surface sediments in the upper intertidal zone increase the rate of oil removal from the beach sediments?
- does the application of fertilizers to the oiled layer of surface sediments in the upper intertidal zone increase the rate of oil removal from the beach sediments?
- what is the natural rate of removal of oil from sediments in the upper intertidal zone?
- what is the behaviour, fate and environmental impact of oil in these spill and treatment scenarios?

4.0 Experimental Overview

The Svalbard field trials were phased over a period of two years. The bulk of planning, organization, and conceptual experimental design took place during the spring and fall of 1996. Site characterization, background studies, some methods development and the oiling of a single control plot were conducted at the experimental site in July/August of 1996. The full scale trials and monitoring were carried out from July to October of 1997. An option also exists for a one year post-trial follow up monitoring of field trial sites to assess the efficacy of experimental treatments relative to natural attenuation.

The basic design elements of the field trials included:

- three separate experimental sites, with test plots nested within a continuous stretch of oiled shoreline at each site.

- one oil type, an intermediate fuel oil, applied directly to the upper intertidal zone sediment surface in a controlled and uniform manner
- full scale treatments conducted after wave and tidal action and stabilization of the oiled zone (about one week after oiling)
- the use of five treatment options; sediment relocation, tilling, bioremediation, tilling plus bioremediation, and natural recovery.
- systematic monitoring of the changes in oil concentrations in the plot sediments over time
- a range of measurements, observations and sample collections carried out within and outside each of the plots, before and following the application of oil and/or treatment to document changes in beach physical character, oil penetration, movement of oil to the sub-tidal environment, toxicity, and oil biodegradation

5.0 Experimental Site

5.1 Location

The field experiments were conducted near the mining town of Sveagruva on Spitsbergen, the largest island in Svalbard (Figure 1). Sveagruva is located on the Van Mijenfjord, approximately 40 km from the open ocean and at approximately 78°56' North and 16°45' East. The ice typically leaves the fjord sometime between early and mid-July. The coastal processes remain active until the beaches begin to freeze over in late November or early December. During the summer period, ambient air temperatures are typically between 0 and 6°C and precipitation between 11 and 20 mm. The salinity in the fjord is approximately 35 ppt and water temperatures range from -1 to 4°C. Summer winds are generally light during the period June through September. The period of strongest winds occurs from November through March, coincidental with the presence of sea ice that prevents wave generation and shore-fast ice that encases the beaches.

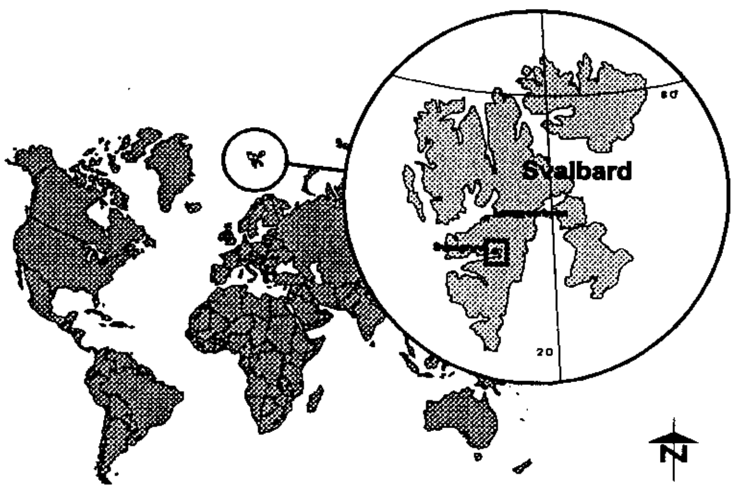

Figure 1. Location of Experimental Test Sites

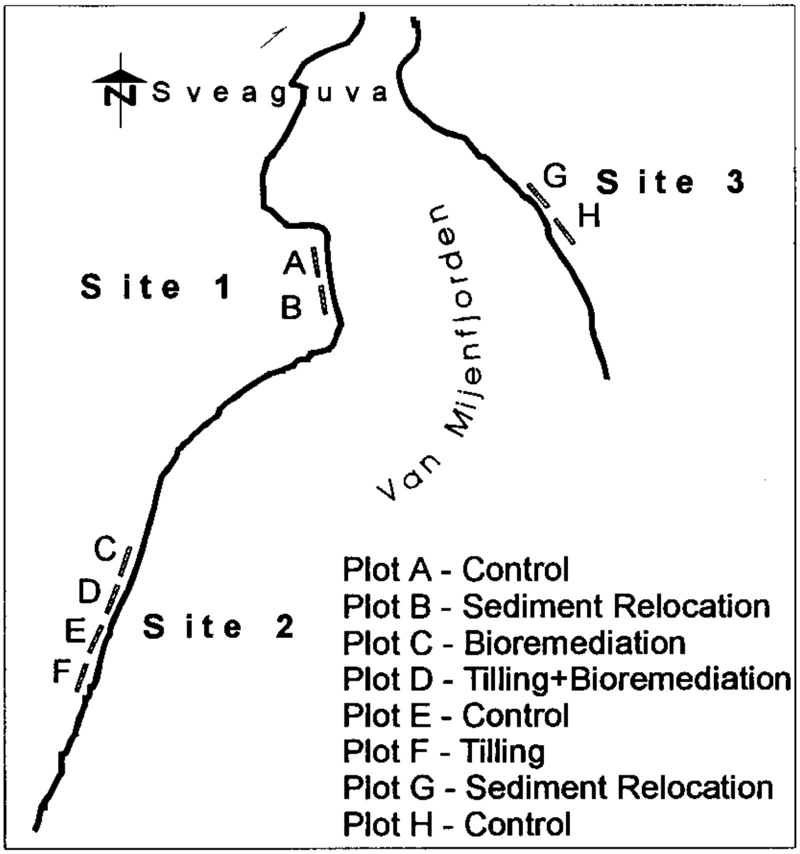

Figure 2. Location of the Test Sites and Plots in the Van Mijenford

5.2 Selection of Experimental Test Sites

Beach surveys were conducted within the Van Mijenfjord during the summer of 1996 to document coastal character and to determine those shoreline segments suitable for the experimental spills. Three specific areas met the selection criteria as candidate sites for experimental work, from the approximately 25 km of shoreline which was assessed (Figure 2). The primary site selection criteria were: (i) mixed coarse sediments, (ii) homogeneous along-shore and across-shore sediment characteristics, (iii) no clay deposits within the top 15 cm of beach sediments, (iv) continuous sections at sufficient length to meet experimental and sampling requirements, and (v) similar wave exposure within each site.

5.3 Physical Environment of the Experimental Test Sites

All three experimental sites have coarse and mixed-sediment beaches of sand and pebble (Figure 3, Table 1). Sites 1 and 2 are very similar, both between plots and between sites, in terms of wave exposure and sediment characteristics. Site 3 has more pebbles and a higher exposure to wave action.

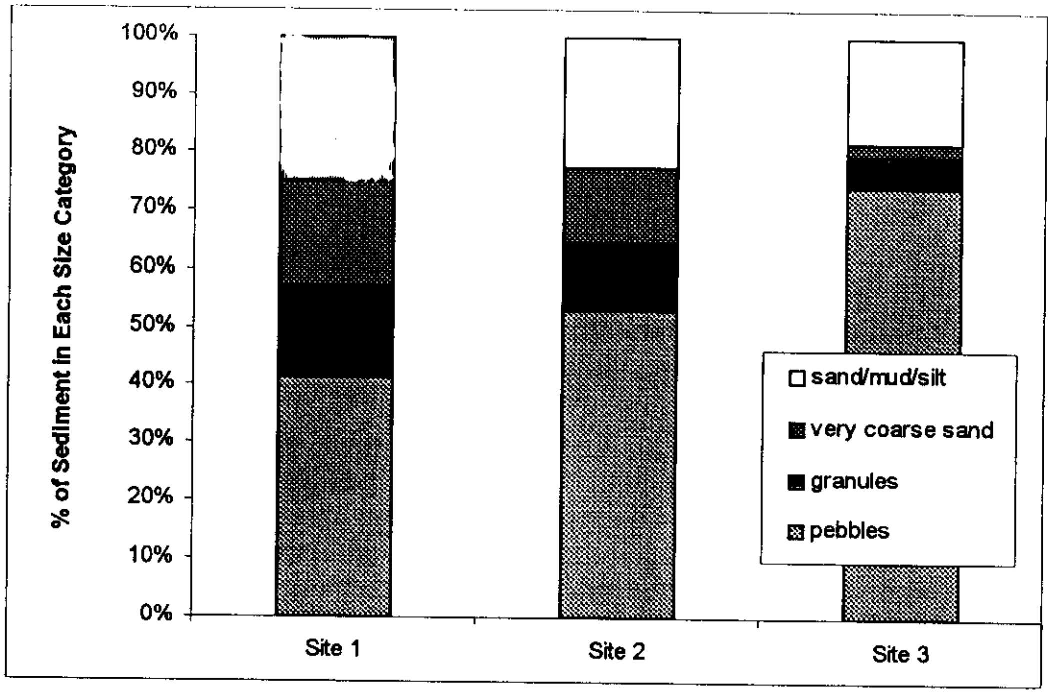

Figure 3. Sediment Grain Size Distribution for the Experimental Sites

Table 1 Summary of Site Characteristics and Treatments

Site	Wave Exposure, Fetch (km)	Sediments (sand:granule:pebble)	Oiling Location	Plot: Treatment
1	Low, 3 km	44:16:40	UITZ	A: Control B: Sediment Relocation
2	Medium, 14 km	36:11:53	UITZ	C: Bioremediation D: Tilling/Bioremediation E: Control F: Tilling
3	High, 40 km	21:5:74	SITZ/UITZ	G: Sediment Relocation H: Control

Site 1 is in a relatively sheltered, wave-energy environment. The beach has a 6- to 8-m wide beach-face slope that gives way to a nearly horizontal low-tide bedrock platform overlain with muds and silts. The platform extends seaward for approximately 100 m and several shallow sections are exposed during low spring tides. The beach is a mixture of sands (44%), granules (16%), and pebbles (40%) and proportionally, has the most sand and least pebble of the three sites.

Site 2 has a 10-m wide beach-face slope that gives way to a shallow sub-tidal environment, with nearshore subtidal water depths of 2 to 3 m at low tide. It has slightly longer wind fetch distances than site 1. This beach is a mixture of sands (36%), granules (11%), and pebbles (53%) with a wide distribution of different sized sediments. A detailed analysis of the sediment grain size data shows that there is no difference in the proportions of sediment types (sands, very coarse sand, granules, and pebbles) with depth, using 0-5 cm, 5-10 cm and 10-15 cm depth intervals. Comparison of the sediment size data from the samples collected over the alongshore distance (within each of the nested four plots) show, that the size distribution does not vary alongshore between plots.

Site 3 is the most exposed of the three beaches used for this study and has an intertidal beach face that is up to 20 m wide. The beach is a mixture of sands (21%), granules (5%), and pebbles (74%) and has the lowest proportion of sands and the highest proportion of pebbles of the three sites. As at the other sites, the sediments were homogeneous in the alongshore and across-shore component of the test plots.

The three study sites were all open to wave action and ice-free during the period of the experiments, mid-July to mid-October. The tidal range is on the order of 0.6 m at neaps and 1.8 m at springs, with a predicted highest water level of +1.82 m and a lowest water level of -0.13 m over the period between July 21 and October 06 1997.

Measured wind velocities generally were less than 10 m/s during the study period, with a maximum measured velocity of 15 m/s. Wave heights greater than 30 cm were not observed during the field study period due to the relatively short fetch areas and the light winds. July and August air temperatures remained above freezing at all times, with daytime maxima that occasionally reached 10°C. Surface inshore water temperature averaged 5.7 °C. By October, the air temperatures had dropped below freezing and the beach had snow patches.

6.0 Oiling and Treatment Methods

6.1 Test Oil and Application

The test oil used in the field experiment was an IF-30, purchased from an Esso refinery in Honningsvåg, Norway. A single batch of oil was obtained at the same time in sufficient quantities to supply all basin and field experiments in order to ensure that the properties of the oil would be the same throughout this series of basin trails and field experiments. The oil is an intermediate fuel oil with an API gravity 18.3 and dynamic viscosity of 757cP at 15°C. The physical-chemical properties are reported in detail in the Catalogue of Crude Oil Properties (Jokuty *et al.*, 1997).

Oil was applied to the test beaches using a custom-built oil application system, which consisted primarily of a perforated polyvinyl chloride (PVC) pipe, a discharge hose and a pump. This system was designed so that the entire across-shore width of the plot (3 metres from top to bottom) could be oiled simultaneously without walking on the oiled area (Figure 4). Even application of the oil to the beach was achieved by moving alongshore at a constant walk rate. Several passes were made over the same area, with a discharge rate between 46 and 48 L/min. Oiling and treatment data are given in Table 2.

Figure 4. Application of Oil to the Test Area at Site 2

Table 2 Oiling and Treatment Data

	Site 1	Site 2	Site 3
Date of Oiling	30.07.97	29.07.97	02.08.97
Date of Treatment	05.08.97	06.08.97	07.08.97
Length of Shoreline Oiled (m)	40	143	80
Width of shoreline oiled (m)	3	3	3
Total oiled area (m^2)	120	429	240
Volume of Oil Applied (L)	900	2200	2400
Resultant Loading (L/m^2)	7.5	5	10
Equivalent slick thickness (mm)	7.5	5	10

6.2 Oil Containment and Recovery

An oil control crew was on site for a three-week period, and was responsible for the containment and recovery of oil lost or removed from the beaches during oiling and treatment (Figure 5). Oiling of the beaches was conducted under controlled conditions, at low tide, with all response equipment in position. Conventional harbour booms were deployed around the entire area to be oiled to prevent loss of oil from the test area on the following high tides. Sorbent booms were deployed along the inside and outside perimeter of the harbour boom. The booms were deployed at high tide and were in place before oiling of the beaches commenced. Intertidal booms were placed at the edges of the plots to be treated prior to treatment of selected sections of beach. These were also lined with sorbent boom.

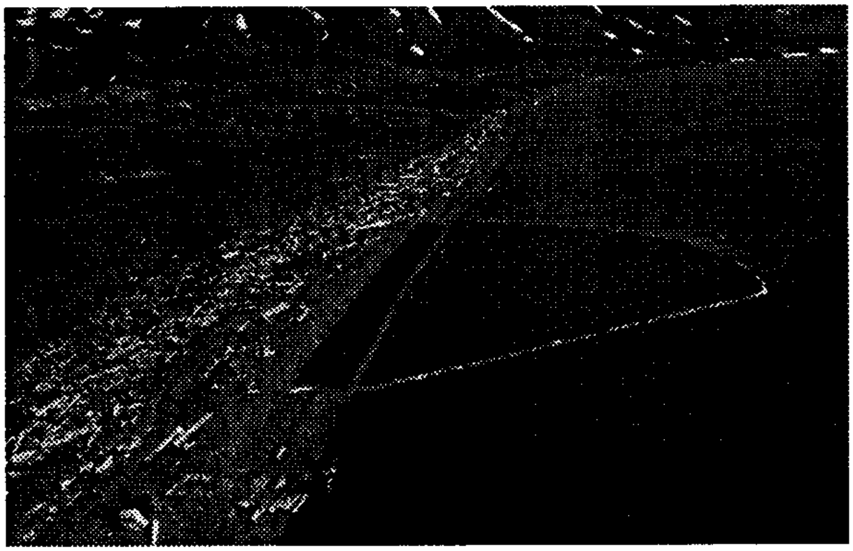

Figure 5. Oiled Beach Section and Boom Deployment at Site 3

The oil control crew was on-site to contain and collect any oil removed from the oiled beaches during the high tides following oiling and treatment. The oil control operations were very successful and at most only a thin sheen of oil was observed to have escaped from the booms.

6.3 Oiling And Treatment with Respect to Tidal Cycles

The timing for the application of oil in the intertidal zone, and the treatment of the test plots was coordinated to match phases of the monthly cycle of spring and neap tides. At sites 1 and 2, the top edge of each plot was located at or just below the spring high water mark. This location placed the oiled test plot (representing stranded oil) in the upper intertidal zone (UITZ), which naturally tends to receive and retain most of the oil during a spill. The oil was applied to sites 1 and 2 during the daily low tide of the neap tide phase, (after which daily tide height began to increase) and then treated at the spring high tide (Figure 6). This strategy was selected both to allow the maximum time for the oil to penetrate the beach sediments, and to allow the plot to be worked by tidal action before application of treatment techniques.

At the higher wave energy site 3, the oil was applied to a zone considerably higher up the beach face than at sites 1 and 2. The top of the plots at site 3 were at the high-water berm of the swash zone, which was well above the spring high tide line. The oiled plot was placed higher on the beach because this is the location where oil would typically strand and persist the longest on this type of beach.

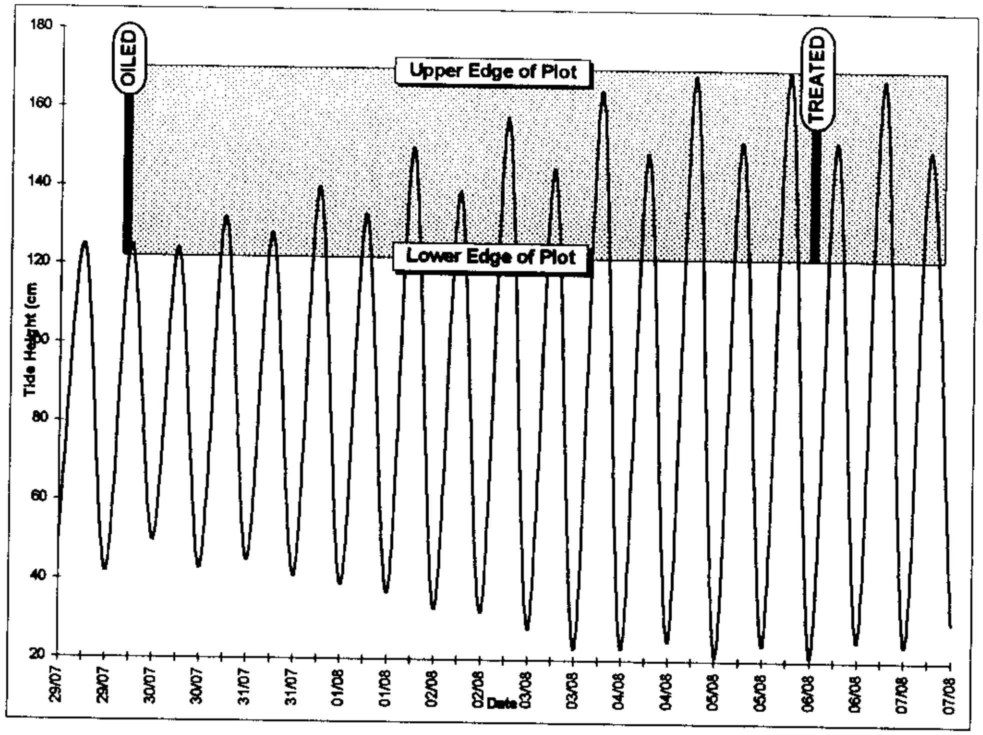

Figure 6. Location of Oiled Plots with Respect to Tides

6.4 Plot Layout

From within each of the three oiled sites, plots were selected for different treatments. The plots were nested within the continuous stretch of oiled shoreline at each site, with oiled buffer zones between plot and at either end of the oiled zone. Sites 1 and 3 each had 2 plots, one for sediment relocation and one control. Site 2 had 4 plots, one each for tilling, control, tilling+fertilizer and fertilizer treatments.

Each plot was subdivided into smaller units (blocs) for systematic sampling within the plots and permanently marked with steel reinforcement bars to facilitate geo-referencing sample location. The sampling area was expanded to include the relocated sediment for plots where the treatment was sediment relocation.

6.5 Treatment of Oiled Plots

Oiled sediments were relocated from the upper intertidal zone to the lower intertidal zone at Site 1 (Plot B) and Site 3 (Plot G) during the low tide period (Figure 7). Approximately one-half of the original zone of oiling at each of these two sites was excavated and redeposited at the waterline with a small front-end loader ("Bobcat"). The loader was operated alongshore, that is the bucket was used in a direction parallel to the water line. Once the bucket was partially filled, the loader backed away from the plot and moved across the beach to deposit the material. Considerable care was exercised to ensure that (a) the bucket was not overfilled, to minimize spillage, and (b) only the oiled layer of sediments was removed and relocated.

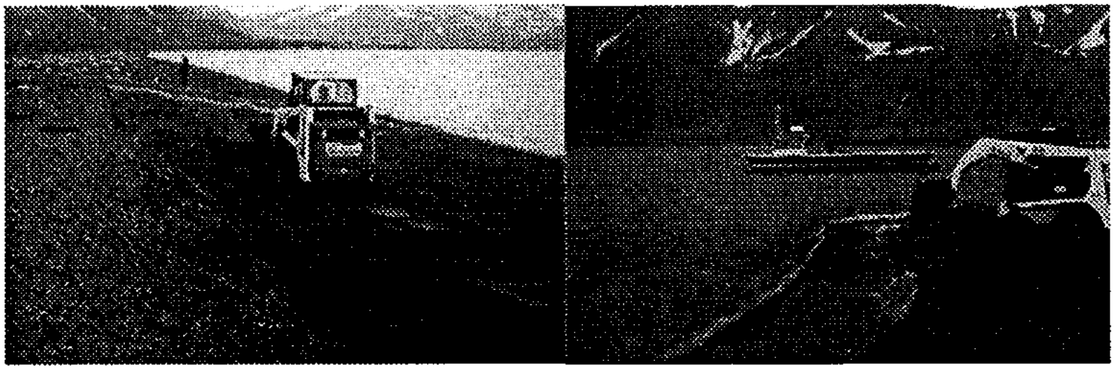

Figure 7. Sediment Relocation at Site 3

Tilling of plots D and F at Site 2 was carried out using a set of tines mounted on the Bobcat's hydraulic arm (Figure 8). The Bobcat was operated in reverse so that the tines were behind the wheels as the vehicle crossed the oiled plots. In each case, the Bobcat was operated from top to bottom across the plot first, followed by a second tilling action alongshore parallel to the water line. The hydraulic arm was operated to ensure maximum disturbance without any surface drag of the sediments by the horizontal tine cross member. The plots were tilled to a depth of approximately 20 cm.

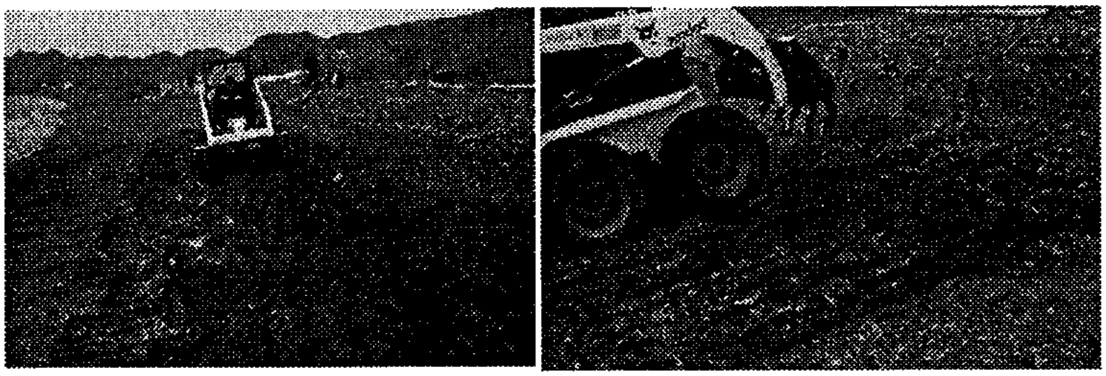

Figure 8. Tilling an Oiled Plot at Site 2

Fertilizer was applied to one of these tilled plots after the first tilling, and also to an untilled plot using a whirligig (Figure 9). The first application of fertilizer, 7 days after oiling, was of ammonium nitrate (Hydro, Sweden), superphosphate (Hydro, Sweden), ferrous sulfate (Christen Hoeg A/S, Norway) and yeast extract (Sigma, USA). The second application of fertilizer, 7 days after the first, was of Inipol SP1 (CECA, Paris La Defense, France), a slow-release formulation containing ammonium phosphate, ferrous sulfate and yeast extract. A third application, of Inipol SP1 was made 16 days later. A fourth application was made in early October, 58 days after the initial treatment. This application was of ammonium nitrate, superphosphate, ferrous sulfate, yeast extract and Inipol SP1.

Figure 9. Application of Fertilizers on Tilled Plot at Site 2

7.0 Measurements and Observations

Sampling, field measurements and observations were carried out in July, August and October 1997. Most observations and sampling fell into the following periods: pre-oiling; immediately before treatment; immediate post treatment and before the first tide; 1 day post-treatment; 5 days post-treatment; 10 days post-treatment; and about 60 days post-treatment (actual time was between 57 and 61 days).

7.1 Wave and Wind Conditions

Weather was monitored periodically during the field trials at each site when on site. These measurements included: wind speed, wind direction, wave height, air temperature.

7.2 Beach Topography Profiles

Beach topography and elevation changes were surveyed along profile lines established by back-shore marker stakes, using the pole and horizon method (Emery, 1960). At least one beach profile line was established on each plot to determine gross changes in form and elevation.

A pin and washer technique was used to more accurately document rises (accretion) and falls (erosion) of the beach surface within each plot At least one pin profile line was established on each plot, with a 25 cm across-shore spacing between pins.

7.3 Sediment Grain Size Determination

Sediment grain size was determined on 1 to 2 kg sediment samples collected between the beach surface and a 15 cm depth. Each sample was air dried and sorted using 64, 32, 16, 8, 4, 2 and 1 mm ASTM sieves in a mechanical shaker. Each size fraction was weighed to the closest 0.5 gm. Mineral fines of the <62μm fraction (silt and clay) were analysed to determine size distribution (laser scattering particle analyser) and mineral composition (x-ray diffraction).

7.4 Background Hydrocarbons

Sediment from site 2 was collected and analysed by gas gas chromotography/flame ionisation detector (GC/FID) and chromotography/mass spectroscopy (GC/MS) to determine if the samples contained coal residue or other hydrocarbons.

7.5 Quantification of Oil within the Experimental Plot

Large volume samples and a systematic sampling methodology were utilized in order to quantify the amount of oil within the experimental plot and the rate of oil loss over time. Nine to twelve samples (one sample per bloc) were collected at each plot at each of five sampling intervals T+0, +1, +5, +10, +60 days. This totalled approximately 400 samples over the 5 collection periods.

Sample location co-ordinates were measured and recorded. A single sample was composed of a vertical composite of sediment from the top of the visibly oiled sediment to the depth of visible penetration of the oil. Surface sediment was removed until the top of the visibly oiled sediment layer was located. Oiled sediment was then removed, until reaching the visible maximum depth of oil penetration, or in some cases, the water table or solid clay. The oiled sediment layer that was removed was then either placed directly into the sample bottles or (in most cases being larger in volume than the container) it was placed into buckets, stirred and then a sub-sample placed into the sample bottle. Regardless of the method, each final sample was about 1.6 to 1.8 L in volume or about 2 kg to 3 kg in weight. The sample bottles were Nalgene 2 L, heavy duty, high density polyethylene bottles with a 53 mm closure. The holes left following sampling were filled in with oiled sediment taken from the buffer zone areas of the plots.

Samples were extracted in the field laboratory using a large sample extraction by dichloromethane (DCM) technique developed during the project. The total petroleum hydrocarbon concentration (TPH) was determined on the oil-in-DCM extract using a gravimetric-determined the total soluble extractable material (TSEM) procedure. In addition, 10% of the samples were analyzed by GC. Toxicity of residual oil in plots from site 2 was analysed by the Microtox® Solid-Phase sediment extraction procedure.

7.6 Depth of Oil Penetration

Measurements of the depth of oil penetration within the plots were made in association with each sample collected for TPH analysis. These measurements provided information on the depth of visibly clean surface sediment and the depth of oil penetration. The information was used to calculate the depth or thickness of the oiled sediment layer.

7.7 Offshore Sub-tidal Sediment Grab Samples

Grab samples of the top 2 cm of mud/fines were collected from the zone directly in front of the plots which were treated by tilling and sediment relocation (to the seaward side of the relocated sediments to determine if any oil or oiled sediments moved from the intertidal plot to the shallow sub-tidal environment. At site 1 and 3, a transect line was run offshore and a SCUBA diver collected samples at distances of 10, 20, 40, 60, 80, and 100 m offshore from the plot. Samples were analysed to determine TPH by GC and toxicity.

7.8 Offshore Sub-tidal Sediment Traps

Benthic sediment traps were positioned 0.5 m off the bottom (75-150 m from the shore), at sites 1 and 3, to measure the sedimentation rate of suspended particulate material. This sedimentary material was characterized for toxicity, mineral composition, and residual hydrocarbon content.

7.9 Water

Water samples were collected in front of each of plots B and F on the first flood and ebb tide after treatment, for extraction and determination of TPH by GC. Pit water was collected from sites 1 and 2 for determination of the presence of Oil-Fines Interaction (OFI) .

Beach interstitial water was collected from within the plots on Site 2, and the levels of fertilizer nutrients (ammonium, nitrate, phosphate) salinity, pH, and dissolved oxygen were measured.

7.10 Alongshore (lateral) Sediments

A qualitative assessment of the movement of oil alongshore was made visually and by collection of 20 sediment samples from the upper intertidal zone at different times and distances away from the plot. These were extracted and analysed with the same methods used for samples within the plots.

7.11 Bioremediation

Interstitial water from the shoreline was obtained from perforated wells installed at four locations on each test plot at Site 2. Samples were collected from within the oiled sediment layer. Samples were also collected just offshore of fertilized and unfertilized plots. Dissolved oxygen, nitrate, ammonium and phosphate levels in the interstitial water were measured using the appropriate Chemetrics kits (Chemetrics, Calverton VA). Salinity and temperature were measured using an Orion 130 conductivity meter (Orion Instruments, Beverly, MA), and pH using an Orion 210A pH meter. Carbon dioxide evolution from the shoreline sediment was measured *in situ* (Swannell *et al.*, 1994) with a Servomex (Crowborough, Sussex, UK) infrared gas analyser. Oil in sediment samples was extracted by methylene chloride, and analysed by GC/MS essentially following published procedures (Douglas *et al.*, 1992).

8.0 Discussion

The analysis of data from the Svalbard field trials is in progress at the time of preparation of this paper. At this time, a few comments can be presented.

The trials were realistic in terms of oiling scenario and the treatment methods considering the conditions expected during actual oil spill response operations. Oiling of the beaches was achieved in a realistic manner in terms of location of the oil with respect to the waterline, the quantities released, and the length of beach oiled. The oil was applied to the beaches where it would realistically be expected to strand in the event of a spill. Sediment was treated in the same way as in an actual response operation, for example in terms of depth of tilling, use of heavy machinery, and/or the ultimate location of the relocated sediment. The response time of one week was also very representative of a feasible response time for a remote location.

The trials were successful from both an operational and an experimental viewpoint, and it seems likely that statistically significant differences in oil concentration between plots and treatments will be obtained. The emphasis given to front-end planning, to designing for statistically defensible data, and the relatively narrow objectives contributed to the success of these trials.

The Svalbard Field Trials have demonstrated, once again, the scientific and operational value of experimental oil spills, particularly as a proving ground for concepts tested in more controlled bench-scale or meso-scale conditions.

9.0 Acknowledgements

The ITOSS Programme is sponsored by an international partnership of oilspill response and research agencies including Canadian Coast Guard, Environment Canada, Exxon Research and Engineering, Fisheries and Oceans Canada, Imperial Oil Canada, Marine Pollution Control Unit (UK), Norwegian Pollution Control Authority, Swedish Rescue Service Agency, Texas General Land Office and U.S. Minerals Management Service.

Thanks are extended to the Governor of Spitsbergen for permission to release oil for this research Programme and to the Store Norske Spitsbergen Kullkompani for their support during the field trials.

The authors would also like to gratefully acknowledge the members of the field team who helped make the Svalbard Field Trials a success. They were: Robert Grant of the Canadian Coast Guard; Patrick Lambert and Zendi Wang of Environment Canada; Rick Bare, Bob Garrett and Matt Grossman of Exxon Research and Engineering; Jonny Berg, Conny Jensen, Christer Lindau and Andars Svensson of the Swedish Rescue Service Agency; Oddveig Bakken, Ana Castanheira and Bror Johansen of SINTEF Applied Chemistry; Jim Nevels of Alaska Clean Seas; and Graham Holtom of AEA Technology.

10.0 References

Bragg, J.R. and E.H. Owens, "Shoreline Cleansing by Interactions Between Oil and Fine Mineral Particles", *Proceedings International Oil Spill Conference*, American Petroleum Institute, Washington, D.C., Publication Number 4620, pp. 216-227, 1995.

Douglas, G.S., K.J. McCarthy, D.T. Dahlen, J.A. Seavey, W.G.Steinhauer, R.C. Prince, and D.L.Elmendorf, "The Use of Hydrocarbon Analyses for Environmental Assessment and Remediation", *Journal of Soil Contam.* Vol. 1, pp. 197-216, 1992.

Emery, K.O., "A Simple Method of Measuring Beach Profiles", *Limnology and Oceanography*, Volume 6, pp. 90-93, 1960.

Jokuty, P., S. Whiticar, Z. Wang, M. Fingas, P. Lambert, B. Fieldhouse and J. Mullin, *A Catalogue of Crude Oil and Oil Product Properties*, Environmental Technology Centre home page: http:/www.etcentre.org/spills, 1997.

Lee, K., T. Lunel, P. Wood., R. Swannell, and P. Stoffyn-Egli, "Shoreline Cleanup by Acceleration of Clay-oil Flocculation Processes", *Proceedings 1997 International Oil*

Spill Conference, American Petroleum Institute, Washington, D.C., Publication. No. 4651, pp. 235-249, 1997.

Lunel, T., R. Swannell, P. Wood, J. Rusin, N. Bailey, C. Halliwell, L. Davies, M. Sommerville, A. Dobie, D. Mitchell, D., and M. McDonagh, "Shoreline Clean up During the *Sea Empress* Incident: the Role of the Surf Washing (Clay-oil Flocculation), Dispersants, and Bioremediation", *Proceedings 19th Arctic and Marine Oilspill Programme (AMOP) Technical Seminar*, Environment Canada, Calgary, Alberta, pp. 1521-1540,1996.

Molden, A., "Response to the *Apollo Sea* oil spill, South Africa". *Proceedings of the 1997 International Oil Spill Conference*, American Petroleum Institute, Washington, D.C., Publication. No. 4651, pp. 777-781,1997.

Owens, E.H., W. Robson, and C.R. Foget, "A Field Evaluation of Selected Beach-cleaning Techniques". *Arctic* 40, Supplement 1:244-257, 1987.

Owens, E.H., A.R Teal, and P.R. Haase, Berm Relocation during the 1990 Shoreline Cleanup Program Following the "Exxon Valdez" Oil Spill. *Proceedings of the 14th Arctic and Marine Oilspill Programme (AMOP) Technical Seminar*, Environment Canada, Edmonton, Alberta, pp. 607-630, 1991.

Owens, E.H., R.A. Davis, Jr., J. Michel, and K. Stritzke, "Beach Cleaning and the Role of Technical Support in the 1993 Tampa Bay Spill", *Proceedings of the International Oil Spill Conference*, American Petroleum Institute, Washington, DC, Publication. No. 4620, pp. 627-634, 1995.

Prince, R.C., "Petroleum Spill Bioremediation in Marine Environments", *Critical Reviews Microbiology* 19, pp. 217-242, 1993.

Prince, R.C. and J.R. Bragg, "Shoreline Bioremediation Following the Exxon Valdez Oil Spill in Alaska", *Bioremediation Journal*, Volume 1, pp. 97-104, 1997.

ʃwannell, ɹ.ϕ.ɲ., ʁ. ɬee, ɑ. βasseres and ʎ.χ. ɯerlin, "ɑ ðirect ɹespirometric ɯethod for ɪn-situ ðetermination of βioremediation ɛfficiency", *ϕroceedings of the ʀ,th ɑrctic ɯarine ɔilspill ϕrogram θechnical ʃeminar*, ɛnvironment çanada, ɔttawa, pp. ʀ,ɜ-ʀ□ɐ,ʀœœʃ.

Sergy, G.A, C.C. Guénette and E.H. Owens, "The In-situ Treatment of Oiled Sediment Shorelines Program"*Proceedings 20th Arctic and Marine Oilspill Programme (AMOP) Technical Seminar*, Environment Canada, Vancouver, B.C. pp. 1353-1363, 1997.